Participation of TacAir-Soar in RoadRunner and Coyote Exercises at Air Force Research Lab, Mesa AZ

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ABSTRACT: *This paper describes the participation of the TacAir-Soar (TAS), intelligent constructive forces in two events hosted by Air Force Research Laboratory, Mesa AZ. The first event, RoadRunner 98, was an aircrew training exercise focused on F-16 pilots and Airborne Warning and Control controllers. TAS provided "aircraft" tracks to improve the air picture and support the training exercise. The second event, COYOTE 98, was a demonstration/experiment for both industry and government officials highlighting new and improved distributed mission training (DMT) technologies.*

1. Introduction

One of the most difficult transitions for emergent technologies is from demonstration systems to the use in ongoing operational systems. To meet the needs of future warfighter training requirements, such as distributed mission training (DMT), computer-generated forces must demonstrate the ability to scale across "all levels of war" (from individual and team participation up to full theater-level battles), execute with minimal operator intervention, and provide high-fidelity behaviors which are indistinguishable from humans performing similar missions. Since traditional computer-generated forces do none of these, the Air Force has turned to its laboratories to evaluate the potential of advanced research projects to prepare aircrews to more effectively use limited flying hours.

This paper discusses the transition of one such system, TacAir-Soar (TAS), from the advanced research state sponsored by the Defense Advanced Research Projects Agency (DARPA) Synthetic Theater or War (STOW) program, into the Air Force Research Laboratory (AFRL), Mesa AZ.

2. Background

In order for a technology transition to be successful there must be a demonstrated need, a promising technology, and an advocate willing to work with the technology and refine it for operational use.

2.1. Background of TacAir-Soar

Soar Technology, Inc. began business with the intention of transitioning the advanced autonomous synthetic forces (TacAir-Soar and RWA-Soar) developed at the University of Michigan and the Information Sciences Institute of the University of Southern California under the DARPA STOW program into the defense forces. The first technology transition was to AFRL, Mesa AZ.

TAS emulates human behaviors for pilots and controllers in the military, fixed-wing aviation domain. RWA-Soar provides behaviors for the rotary-wing domain. They have been under development since 1992. This paper will focus primarily on TAS.

The goal of TAS intelligent constructive forces is to develop human-like synthetic entities for populating simulation environments. In contrast to semi-automated forces, where it is assumed some higher level entity will be responsible for decisions requiring judgement, our approach is to endow all entities with knowledge and decision making abilities similar to humans performing similar tasks. This approach, confirmed in part by participation in numerous military events, such as those described here, is that building intelligent forces provides a payoff in terms of increasing the fidelity of the entity's behavior, while decreasing the complexity of command.[9]

What distinguishes TAS from other approaches to computer-generated forces is that the entities are

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truly autonomous and unscripted. Once tasked they carry out their assigned missions, react to threats, coordinate their actions, and communicate with other entities without requiring any human intervention. If human intervention is desired, it happens in the way real-world interactions occur, through mission orders transmitted on radios or data links.

It accomplishes this by integrating a wide range of intelligent capabilities, including real-time hierarchical execution of complex goals and plans, communication and coordination with humans and simulated entities, maintenance of situational awareness, and ability to accept new orders while in flight.[4]

TAS was designed for a very large-scale (i.e., theater-level with thousands of units), all-synthetic environment. In STOW 97, TAS demonstrated the ability to generate autonomous, real-time, high fidelity behavior for a large-scale simulation of a complete theater battle.[5]

The AFRL facilities at Mesa provide a way to exercise TAS's capabilities from the individual combatant (flying one on one or as a wingman), to an integrated part of a strike package, and as part of a full air war in a mixed human environment. Within this environment, the lab is a microscope for behavior validation because of the high-fidelity graphics and tight formations from the virtual cockpits. For example, we were pleased with the high quality of formation flying and tactical turns, but also observed jerkiness in flight corrections and other faults not detectable by more casual observation.

2.2. AFRL, Mesa AZ

The Warfighter Training Research Division (AFRL/HEA) in Mesa, AZ is part of the U.S. Air Force Research Laboratory within Air Force Materiel Command (AFMC). It is the USAF's premier organization for research and development in aircrew training techniques and technologies. The division's mission is to "develop, demonstrate, evaluate, and transition training technology and methods to train warfighters to win." The mission is accomplished through an open collaborative environment in which government, academia, and industry team with users and customers to develop and exploit new technologies, applications, and environments that will support the warfighter. The collaboration is designed to improve development, validation, and transition of needed training products to users, customers, and solution providers supporting the premise of "training the way we intend to fight" and recognizing that "training is the peacetime manifestation of war."

The integrated nature of war, high tech threats, and military operations other than war are creating a burgeoning training challenge for the USAF and joint forces. Coupled with the need to process extraordinary amounts of data and information, from sensor to Joint Forces Air Component Commander (JFACC) to shooter and back again, warfighters require seamless operational systems and a peacetime integrated operations environment that will provide realistic mission training opportunities that currently do not exist. The need for realistic training is complicated by concerns with aging aircraft, training environment encroachment, expanding operations tempo, and cost. Classical individual procedural-based training must be supplemented by full-mission training to adequately prepare warfighters for the challenges of the 21st century. Consequently the USAF has embarked on revolutionizing training initiatives that advocate affordable, realistic training environments to reduce the dependence on the aircraft as the primary training media. Modeling and simulation is expected to provide on-demand, realistic training opportunities through an integrated operations environment composed of live, virtual, and constructive training capabilities.[1]

3. Transition to AFRL

Watching and working closely with the STOW technology development efforts since 1993, it was obvious to HQ USAF/XOC that STOW technology would improve the training environment for aircrews. In early 1994, STOW experiments in Europe blended a manned Air Force F-15E simulator, the Lockheed Martin F-16C FalconStar, an AF ground FAC in a virtual "visual ground controlling" CAS environment, and Army SIMNET trainers. Thereafter, the Air Force leaned toward integrating manned simulators into the STOW synthetic battlespace. Of course, funding, or lack thereof, was the keystone. It was 1997 before any significant effort began to bring STOW technologies to the Air Force Manned Simulator development at AFRL, Mesa AZ. There for the first time the Air Force began to wring out the technology in an Air Force laboratory environment, funded by both the STOW transition effort and the United States Air Force Directorate of Command and Control (HQ USAF/XOC).

The crown jewel of the STOW effort appeared to be the TAS and other computer-generated forces. They appeared of sufficient fidelity to support training, were cost effective to populate the battlespace,

and were adaptable for multiple applications and implementations in the lab testbed. In particular, the ability to interface TAS to both the Distributed Interactive Simulation/High Level Architecture (DIS/HLA) network environment, and voice linkage to humans opened exciting opportunities for leaps in training applications.

The process of bringing STOW technologies to AFRL consisted of three phases. First was a look at the synthetic forces, those representations of aircraft and appropriate behaviors (specifically TAS)--how well do they blend with manned simulation. Second, bring the unique STOW synthetic environment into the existing Lab network for initial evaluation. Then take a creative initial look at an assortment of technologies to find the best and the brightest. Third, merge those appropriate technologies into the Distributed Mission Training environment under creation at this time.

The first phase was RoadRunner '98, including a high resolution look at TAS support for a manned trainer environment. In COYOTE, the second phase, the technologies were blended, contorted, and melded into a unique supporting environment in ways never before achieved. And the third phase, well, that's a military/industrial secret.

4. RoadRunner ’98

RoadRunner '98 was a Distributed Mission Training exercise sponsored by HQ USAF/XOC. It was developed as a training exercise. The whole purpose was to immerse aircrews into a virtual battlespace to optimize their training--bring fighter crews for predeployment training; incorporate wing training officers and intelligence specialists, and fly crews twice per day in a weeklong exercise. As Red Flag spin-up training, the battlespace was geographically the Red Flag environment including multiple aircraft types and airborne command and control. Behavioral lab scientists observed and measured performance to validate the training value of the experience.

RoadRunner ’98 was conducted at various operational and research and development facilities across the US from 13-17 July 1998. The main facilities were AFRL Mesa, AZ; the Theater Air Command and Control Simulation Facility (TACCSF) at Kirtland AFB, NM; the Airborne Warning and Control System (AWACS) trainers at Tinker AFB, OK; and the Air Force Information Warfare Center (AFIWC) at Kelly AFB, TX. [2]

Participants in RoadRunner ’98 formed several mission teams, each consisting of F-16, F-15, and A-10 pilots, plus weapons directors (WD) and air surveillance technicians (AST) from AWACS. Training was focused on the pilots in the manned virtual cockpits at both AFRL/HEA and TACCSF, as well as the WDs and ASTs at Tinker AFB. F-16 pilots from Cannon AFB, NM, and the Iowa Air National Guard (ANG) flew four AFRL/HEA F-16 Multitask Trainers (MTT). The MTT is equipped with a Mobile Modular Display for Advanced Research and Technology (M2DART), which provides a 360-degree, out-the-window visual display. The A-10 pilots from Davis-Monthan AFB, AZ, served as forward air controllers and flew an AFRL/HEA A-10 MTT, equipped with an earlier generation DART visual display. At TACCSF, pilots from Eglin AFB, FL; PACAF; TACCSF; and AFRL/HEA flew Boeing F-15 Weapons and Tactics Trainers (WTT) equipped with a single-channel, forward visual display system. Additionally, TACCSF provided two MiG-29 Virtual Red Air Stations flown by adversary tactics pilots from Nellis AFB, NV. WDs and ASTs, using a virtual E-3 AWACS simulator, were assigned to each team and participated from their home station at Tinker AFB, OK. White Cell and Intelligence Officers were also key players from the operational units and helped increase the realism of the training scenario. [2]

Computer-generated forces included F-16Cs (generated by TAS), 3 AH-64s, 3 Mi-24 Hinds, all computer generated by Synthetic Theater of War technology, 3 KC-135s, 10 MiG-29s, 2 SU-27s, and 5 ZSU-23-4 antiaircraft artillery (AAA) units generated by the AFRL/HEA Automated Threat Engagement System (ATES), and M-1 and T-72 tanks from ModSAF. TACCSF constructive forces included one E-3 AWACS. A robust Integrated Air Defense System (IADS) from AFIWC included one SA-2 surface-to-air missile (SAM), 5 SA-6 SAMs, 3 SA-8 SAMs, a Height Finding Radar, and an Early Warning Radar system.[2]

The primary role of TAS controlled aircraft in RoadRunner was to enhance the scenario by providing realistic forces flying in strike packages with other computer-generated forces and with manned simulators. With AFRL’s four F-16s being the only manned elements in the strike packages, TAS was needed to populate these packages with more aircraft on the same type of operational mission. The results were the pilots receiving the training were immersed into a realistic, complex battlefield arena. A key advantage of using TAS was the ability to easily tailor the strike packages and adjust the level of the complexity desired for each training sce-

nario. TAS flew over 200 sorties during the five-day training exercise.

Primary missions included suppression of enemy air defenses (SEAD) and deep strike missions against enemy airfields. During these operational missions TAS aircraft employed a variety of munitions including Mk –82 bombs, AGM-88 HARM s, AIM-120 AMRAAMs and AIM-9 Sidewinder missiles.

This was a novel use of these constructive forces because it was the first time they were used as friendly forces in close proximity to manned simulators. These joint missions were coordinated by time, location, and speed. TAS aircraft were expected to be at a rendezvous point at a given time to join up with the virtual trainers. Once joined, they were directed to push from the point and begin their ingress route. Because the package was loosely joined, coordination along this route depended on maintaining speed. As the SEAD and strike aircraft approached their targets, the escorts would split off, and rejoin for the egress.

At least that's the way it was supposed to work. In practice, once the package crossed into bad-guy territory, all hell broke loose. The aircraft found themselves under attack from enemy air and ground forces. If the escorts did not do their job, the TAS aircraft would have to abandon their primary missions to fight their way on to their targets. This had a ripple effect, since preventing the SEAD mission from performing its job meant that the strike mission would probably be destroyed by ground fire. Since the target of the strike was an air base, not only would another strike be required to finish the job, but more enemy aircraft would be available to disrupt the egress.

During the first two days of the exercise, TAS aircraft scored more air-to-air kills than the pilot trainees. While this was good from a TAS perspective in demonstrating mission flexibility and performance quality, it was undesirable from a mission perspective, because the TAS aircraft were too busy chasing enemy aircraft to perform their primary missions. By the third day, pilot performance had increased to the point where they were about equal, and by the end of the week, the trainees were able to perform their missions with sufficient effectiveness that the TAS aircraft almost always reached their intended targets.

One of the government's key requirements for a CGF is that it be indistinguishable from a human. RoadRunner presented us with an opportunity to perform such testing, and evidence that TAS behavior was difficult to distinguish from human performance came when a pilot was separated from his flight leader by the "fog of war." The pilot joined up with a TAS-controlled aircraft's visual model and flew some distance before an exercise controller corrected the action.

Another requirement for a CGF is that behaviors can be verified and validated. In the past, TAS has approached this problem in several ways: first, by providing traceability via hyperlinks between the rules that implement the behaviors and the supporting documentation, doctrine, and interviews with subject matter experts; second, by providing run-time inspection of the entity's decision making process; and third, through evaluation by subject-matter experts. As a result of these experiments, the subject-matter experts wanted a better understanding of the inputs to the decision making process than inspection of the system inputs. The Situational Awareness Panel, a graphic display of the entities awareness of the situation combined with the resultant decision process, was developed to provide this insight.

5. COYOTE '98

COYOTE '98 was an AFRL- and HQ USAF/XOC-sponsored event. It was basically an "Industry Day," in both classified and unclassified formats, designed to highlight new technologies.

The rules were simple--truth in advertising. What was shown must be working demonstrations, performing as "advertised," and pass the acid test of credibility. Unique and creative applications were encouraged in the context of future DMT capabilities.

For the COYOTE demonstration TAS was used to showcase a variety of new technologies supporting DMT concepts. TAS-controlled aircraft participated in several events including low-level strikes against a synthetic environment. Two separate air control systems were used, the first was live weapons controllers based at the TACCSF at Kirtland AFB, NM, interacting with TAS aircraft through a voice interface; the second replaced the human AWACS controllers with the Cognition Oriented Emergent Behavior Architecture (COREBA), an experimental architecture developed by Lockheed Martin. Finally, TAS aircraft participated as a synthetic wingman with the TAS "aircraft" flying in tactical formation with a manned F-16 simulator. The TAS performed wingman functions interacting through radio/voice communications with the manned simulator as the two "aircraft" sorted and engaged air-to-

air enemy targets while maintaining mutual support.

COYOTE was conducted primarily using the High Level Architecture, though some demonstrations with other simulators required the use of Distributed Interactive Simulation. TAS is built on top of JointSAF, which supports both HLA and DIS.

5.1. Virtual Control of Constructives

The intent of this scenario was to demonstrate the capability for human weapons controllers, in a virtual AWACS simulator at TACCSF, to direct and control intelligent computer-generated forces in air-to-air combat.

This was a continuously fed airfight. As aircraft were lost, the controllers were free to scramble additional forces on ground alert, and as red forces were destroyed, new threats were generated. In order for the interaction to be as realistic as possible we used commercial off-the-shelf software to convert the controller's voice directives to text messages which were then passed over simulated radios. Responses were passed along these same radios and synthesized to speech, so the controllers could hear the responses over their headsets. The specialization of this system for the military air domain is called SoarSpeak.

Once the controllers were trained in the vocabulary, the TAS aircraft were able to carry out the controller's orders directly without any intervention from an operator. Though TAS is unable to understand arbitrary directives, it demonstrated a wide range of directives and control of the aircraft. In the air domain, the problem of understanding arbitrary directives is mitigated by standard "comm brevity terms."

5.2. Synthetic Wingman

The most ambitions project undertaken for this demonstration was a TAS entity flying formation with a human pilot in a virtual cockpit.

Once again, SoarSpeak was used to convert speech directives to text and vice versa. This allowed the lead aircraft to commit against enemy aircraft, sort targets, and modify the tactical formation.

TAS maintained good formation with the virtual cockpit, performed independent targeting, and demonstrated close coordination.

TAS performed sufficiently well that the operators took turns rotating new pilots through the virtual station to test the capability to speech understandingin in a high noise environment, and to account for individual differences. With literally five minutes training in the vocabulary, a new pilot was able to lead TAS-controlled aircraft into combat.

A humorous event emphasized this fact. As the first pilot was attempting to "control" his wingman, his lexicon was less than precise. Consequently, the TAS wingman moved out of visual range of his lead aircraft. When flight lead (the human pilot) directed him to turn to heading 270, the TAS aircraft responded "Roger, authenticate XYZ" while maintaining his current vector. The TAS wingman was complying with theatre procedures that required him to verify unknown directives with coded authentication procedures. When the lead pilot authenticated accurately, the TAS wingman immediately followed lead's directions, and successfully rejoined the number 1 aircraft. At that point we knew we had a "novice pilot" as wingman, but maybe both could learn from each other.

5.3. Low-Level Strike over Synthetic Environment

Another capability to come out of the STOW program was a dynamically managed representation of the synthetic environment, including effects such as weather, smoke plumes, multi-state objects, craters, and tank ditches.[3]

When bombs impact the targets, which were either runways, hangers, buildings or oil storage tanks, they showed either partial damage or collapsed into a pile of rubble.

In another demonstration a computer simulation model generated different types of weather conditions, low to medium clouds and a severe dust storm, while an airstrike was underway against an airfield. TAS considers visibility in the target area and, on both final attacks, had to abort due to poor visibility**.**

For this demonstration, TAS-controlled aircraft flew low-level precision bombing runs into this synthetic environment with virtual aircraft trailing to illustrate the effects and perform battle damage assessment.

Once briefed, these missions flew completely autonomously through to their targets. All runs flew successfully.

5.4. Interaction with Synthetic AWACS

For the final TAS demonstration, a synthetic weapons director controlled by COREBA[7] replaced human weapons directors at TACCSF. Though TAS has its own model of a weapons director, it

was unclear whether TAS aircraft could be controlled by other CGF systems.

TAS controlled 40 aircraft directed by COREBA. JointSAF task frames controlled opponent aircraft. Once again, this was a continuously fed airfight. As aircraft were lost, the controller was free to insert additional forces, and as red forces were destroyed new threats were generated.

COREBA was a Lockheed Martin Information Systems effort using a combination of artificial intelligence techniques (Fuzzy CLIPS rules, Swarm objects, Objective C objects, and Genetic Algorithms) to replicate some of the coordination functions aboard the AWACS platform. Essentially, COREBA organized the flow of tactical aircraft into a large, feed-the-fight type of air battle. It capitalized on the autonomous characteristics of TAS entities. TAS accomplished all tactical end-game actions. COREBA was able to interface across the net by capitalizing on the ability of the TAS aircraft to respond to radio control messages.

6. Ongoing Work at AFRL

The training accomplished during RoadRunner was so successful that AFRL conducted another exercise for two weeks in early 1999. The training scenarios request by the fighter squadrons were similar to RoadRunner but included more offensive counter-air and fighter escort missions. Once again TAS was an integral part of the training environment. This time TAS expanded its role to include enemy fighter sweeps, interdiction, and high/fast reconnaissance missions. The responsiveness of TAS was highlighted during these training sessions when the manned fighters did an excellent job and had killed all the programmed enemy in a certain time frame. During this lull in the action, TAS was selected to launch a high and fast reconnaissance aircraft which created a difficult interception problem for the pilots. It is hoped that exercises like this will now happen on a bimonthly basis. It is during these types of training events that TAS is improved by the program managers attending the debriefings sessions and by talking to the pilots about the actions of TAS aircraft and what they would like to see future operational capabilities of TAS.

One of the future capabilities will be the integration of missile countermeasures. Currently TAS aircraft perform tactical maneuvers to avoid missiles. We are pursuing the addition of chaff, flares, and jamming to challenge pilot trainees and increase the ability to "train the way we fight."

7. Comments

"From the HQ USA/XOC perspective, TAS was essential to COYOTE '98. The ability to interface via speech recognition and text transmission real-time to multiple other applications and environments was instrumental to multiple integrations. The flexibility of the TAS software was simply outstanding." -- JD

Allow JD to share the secrets to this successful integration effort in terms of mechanics, practicalities, and politics. The mechanics were simple in theory: find talented technologists with incredible software implementations of "near reality" for the air domain. Done--complements of the STOW program. Practicalities: it takes money, so go find some. That is a difficult issue in today's funding environment, so creativity reigned, and was somewhat successful. Politics: find ways to leverage multiple programs into a win-win situation for all concerned, then take the technologists, sprinkle with just enough money to get by, and declare victory. Seriously, the secret was the dedicated individuals involved in this effort combined with the support of management, programs, institutions, and industry all assisting this project.

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Author Biographies

Paul E. Nielsen is President and one of the co-founders of Soar Technology, Inc. an intelligent, simulation software company. He received his Ph.D. in computer science from the University of Illinois in 1988. Prior to joining Soar Technology he worked at the GE Corporate Research and Development Center and the University of Michigan Artificial Intelligence Laboratory. His interests include intelligent agent modeling, qualitative physics, machine learning, and time constrained reasoning.

Don Smoot works for the Lockheed Martin Technology Services Group supporting the AFRL Warfighter Training Research Division in Mesa AZ. He is currently the program manager for the STOW Computer Generated Forces research and development activities there. His background includes 11 years in the Air Force as a command and control (C2) Air Battle Manager at ground sites and in AWACS aircraft. Additionally he spent 10 years in AFRL as a senior AF manager in C2 research.

JD Dennison is currently semi-retired and in an entrepreneurial enterprise. Formerly an F-4 Phantom Weapon System Officer, trainer, staff officer, and exercise planner for the premier USAF wargaming center, his last active duty position was as a staff officer at HQ USAF Directorate for Modeling and Simulation in the Pentagon. There he was responsible for virtual simulations and Air Force participation in the STOW program. After retirement, he continued as a SETA to HQ USAF/XOM and then XOC as the directorate evolved. His interests include family, travel, music, and fishing. His main claim to fame was his additional duty as AF Social Director at CGF conferences.